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APPLICATION FOR UNITED STATES LETTERS PATENT

for

HIGH TEMPERATURE FLEXIBLE PIPE JOINT

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BACKGROUND OF THE INVENTION

1. Field of the Invention.

[0001] The present invention relates to a flexible pipe joint for subsea risers and pipelines, and in particular, such a flexible pipe joint that is capable of long-term operation when subjected to temperatures greater than about 180 °F (82 °C).

2. Description of the Related Art.

[0002] Offshore production facilities typically use risers constructed of rigid pipe sections and flexible joints for conveying production fluid such as oil or gas from a well on the seabed to a floating offshore production platform. This construction, for example, permits a pipeline to be laid under water and then raised for connection to the offshore production platform.

[0003] Typically, a flexible pipe joint has a laminated elastomeric-flex element including alternating layers of elastomer and steel plates. The elastomer is bonded to the steel plates and the steel plates are encapsulated in the elastomer. The elastomer is typically vulcanized natural rubber, synthetic rubber, or mixtures of natural and synthetic rubber. Such flexible pipe joints have been designed and manufactured for a service life of at least twenty years under low temperature conditions.

[0004] As described in Whightsil, Sr. et al., U.S. Patent 5,133,578, the flexible pipe joint may also include a bellows to isolate the elastomeric flex element from gases in the production fluid. For example, if the elastomer were exposed to high-pressure production fluid containing low molecular weight gasses such as methane, explosive decompression could occur upon sudden release of the high pressure, causing

1 gas molecules captured in the elastomer to expand and cause local ruptures in the
2 elastomer surface.

3 [0005] Recently there has been a need for flexible pipe joints that are capable
4 of long-term operation when subjected to temperatures greater than 180 °F (82 °C). In
5 particular, wells are being drilled into the seabed at depths of more than 1000 meters in
6 the Gulf of Mexico and off the shore of Nigeria. It is desired to use flexible pipe joints in
7 risers for delivering production fluid from the wellhead on the seabed to a floating
8 platform. However, the planned depths of the wells below the seabed and the desired
9 high flow rates would cause the temperature of the production fluid to substantially
10 exceed 180 °F (82 °C). In addition, the ambient seawater temperature is relatively high
11 (80 to 85 °F (27 to 29 °C)). If a conventional flexible pipe joint were used to convey the
12 production fluid, the flex element in the flexible joint would be continually subjected to
13 temperatures in excess of the usual limit of 180 °F (82 °C). This would cause the service
14 life of the conventional flexible pipe joint to be severely degraded. Therefore, there is a
15 desire for a high temperature flexible pipe joint that would have a service life of at least
16 twenty years when conveying production fluid at temperatures considerably in excess of
17 180 °F (82 °C).

19 SUMMARY OF THE INVENTION

20 [0006] In accordance with one aspect, the invention provides a high
21 temperature flexible pipe joint. The high temperature flexible pipe joint includes a body,
22 and extension pipe, and a laminated elastomeric flex element coupling the extension pipe
23 to the body. The laminated elastomeric flex element has alternate elastomer layers and

1 reinforcement layers including inner layers near to the extension pipe and outer layers
2 away from the extension pipe. The flex element is constructed to shift strain from the
3 inner elastomer layers to the outer elastomer layers.

4 [0007] In accordance with another aspect, the invention provides a high
5 temperature flexible pipe joint. The high temperature flexible pipe joint includes a body,
6 an extension pipe, and a laminated elastomeric flex element coupling the extension pipe
7 to the body. The laminated elastomeric flex element has alternate elastomer layers and
8 reinforcement layers. The high temperature flexible pipe joint further includes a heat
9 shield disposed in the extension pipe in the vicinity of the laminated elastomeric flex
10 element.

11 [0008] In accordance with yet another aspect, the invention provides a high
12 temperature flexible pipe joint for continuous operation over a service life in excess of
13 twenty years. The high temperature flexible pipe joint includes a body, an extension pipe,
14 and a laminated elastomeric flex element coupling the extension pipe to the body. The
15 laminated elastomeric flex element has alternate elastomer layers and reinforcement
16 layers including inner layers near to the extension pipe and outer layers away from the
17 extension pipe. At least an innermost elastomer layer is made of high temperature
18 resistant elastomeric material, and the laminated elastomeric flex element is constructed
19 to shift strain from the inner elastomer layers to the outer elastomer layers. The high
20 temperature flexible pipe joint further includes a heat shield disposed in the extension
21 pipe in the vicinity of the laminated elastomeric flex element. Moreover, the extension
22 pipe is made of low heat conductivity metal in the vicinity of the laminated elastomeric
23 flex element.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Other objects and advantages of the invention will become apparent upon reading the following detailed description with reference to the accompanying drawings wherein:

[00010] FIG. 1 shows the use of high temperature flexible pipe joints of the present invention for conveying production fluid from a wellhead on a seabed to a floating production storage and offloading facility (FPSO);

[00011] FIG. 2 shows an example of a high temperature flexible pipe joint in accordance with the present invention;

[00012] FIG. 3 is a lateral cross-section of the high temperature flexible pipe joint of FIG. 2;

[00013] FIG. 4 is a magnified view of an upper bellows seal area in FIG. 3;

[00014] FIG. 5 is a magnified view of a lower bellows seal area in FIG. 3;

[00015] FIG. 6 is an exploded view of components in a heat shield disposed between a riser extension and an elastomeric flex element in FIG. 3;

[00016] FIG. 7 shows an enlarged cross-section of the elastomeric flex element in FIG. 3;

[00017] FIG. 8 shows an enlargement of the cross-section in FIG. 7;

[00018] FIG. 9 shows an alternative construction for the elastomeric flex element in which two different kinds of elastomer are used in the flex element;

[00019] FIG. 10 shows an alternative construction for a flexible pipe joint for using temperature resistant elastomer that exhibits poor bonding to metal at high temperature or has a low strain limit at high temperature;

1 **[00020]** FIG. 11 shows an enlarged cross-section of the elastomeric flex
2 element in FIG. 10;

3 **[00021]** FIG. 12 shows an alternative construction for heat shielding in a high
4 temperature flexible pipe joint;

5 **[00022]** FIG. 13 shows another alternative construction for heat shielding in a
6 high temperature flexible pipe joint;

7 **[00023]** FIG. 14 shows an alternative construction for a high temperature
8 flexible pipe joint having a finned body for enhanced heat transfer to the ambient
9 seawater environment;

10 **[00024]** FIG. 15 is a lateral cross-section of the high temperature flexible pipe
11 joint in FIG. 14; and

12 **[00025]** FIG. 16 is a transverse cross-section along section line 16-16 in FIG.
13 15.

14 **[00026]** While the invention is susceptible to various modifications and
15 alternative forms, specific embodiments thereof have been shown by way of example in
16 the drawings and will be described in detail. It should be understood, however, that it is
17 not intended to limit the invention to the particular forms disclosed, but on the contrary,
18 the intention is to cover all modifications, equivalents, and alternatives falling within the
19 scope of the invention as defined by the appended claims.

20 21 **DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS**

22 **[00027]** With reference to FIG. 1, there is shown a steel catenary riser (SCR)
23 generally designated 10 for conveying production fluid such as oil or gas from a well

1 head 11 on the sea bed 12 to a floating production storage and offloading facility (FPSO)

2 13. The FPSO 13 is essentially a supertanker provided with a derrick 14 capable of
3 deploying and retrieving drill strings and risers to and from the seabed 12. The steel
4 catenary riser 10 is comprised of steel pipe sections e.g. 15, 16, 17 interconnected by
5 flexible pipe joints 18, 19.

6 [00028] For a well that has been drilled very far below the seabed 12, the
7 production fluid issuing from the wellhead 11 may considerably exceed 180 °F (82 °C)
8 especially for very high flow rates. For example, the maximum production fluid
9 temperatures expected for high flow rates from deep offshore wells currently being drilled
10 are generally in the range of 240 °F (115 °C) to 265 °F (130 °C), and it is not
11 inconceivable that future offshore wells could have production fluid temperatures as high
12 as 350 °F (177 °C). Depending on the temperature of the production fluid, the ambient

13 seawater temperature, the flow rate of the production fluid, and characteristics of the
14 production fluid such as its heat capacity and viscosity, and the configuration and
15 properties of the materials in the flexible pipe joint, the high temperature production fluid
16 may cause the elastomeric flex element in a flexible pipe joint to be subjected to a
17 temperature in excess of its continuous operation design temperature limit for a desired
18 service life.

19 [00029] In the worst case, continuously subjecting an elastomeric flex element
20 in a flexible joint to a temperature above its design temperature limit could lead to a
21 failure of the elastomeric flex element before the end of its service life. Typically the
22 elastomeric flex element functions as a pressure seal as well as a flexible bearing.
23 Therefore, a failure of the elastomeric flex element due to excessive temperature exposure

1 could cause an undesired spill of production fluid in addition to a need for shutting down
2 production during replacement of the flexible joint.

3 [00030] In practice, if flexible pipe joints are not available for handling the
4 high production fluid temperatures that would result from high flow rates from deep
5 offshore wells, it may not be possible to obtain the desired high flow rates from the wells.
6 Instead, the flow rate would need to be restricted to limit the production fluid temperature
7 to the highest temperature that could be continuously tolerated by the flexible pipe joint
8 over its desired service life.

9 [00031] FIG. 2 shows an external view of a high temperature flexible pipe joint
10 18 that has a variety of features for achieving a conventional service life when subjected
11 to high temperature production fluid. The flexible pipe joint 18 includes a cylindrical
12 body 21, an attachment flange bolted to an upper end of the body, and an extension pipe
13 23 depending from the body. The flexible pipe joint 18 could be made to handle various
14 production fluid pressures and flow rates. For example, a standard kind of pipe is known
15 as 12 inch high-pressure pipe capable of handling at least 10,000 psi. To join such 12-
16 inch high-pressure pipe, the flexible pipe joint 18 may have an inner bore diameter of 9.6
17 inches (24.4 cm), a 13.5 inch (34.3 cm) outer diameter of extension pipe, a maximum
18 outer diameter of 62 inches (157 cm), and a height of 82.5 inches (210 cm) (excluding the
19 length of the extension pipe). The extension pipe 23 has a maximum angular deflection
20 of ± 17 degrees with respect to the body 21. The extension pipe 23 can support a
21 maximum axial tension of 1,500 kips, and provide an extreme angle deflection stiffness
22 of about 15 to 40 kips per degree. The body 21, attachment flange 22, and the portion of
23 the extension pipe 23 depending from the body are preferably made of ASTM A707 steel.

1 ASTM 707 is a high-strength, low carbon steel that resists hydrogen embrittlement from
2 hydrogen sulfide, and does not require welds to be stress relieved after welding.

3 **[00032]** FIG. 3 is a lateral cross-section of the high temperature flexible pipe
4 joint 18. The flexible pipe joint has radial symmetry with respect to a longitudinal axis
5 24, which is the central axis of a bore 30 in the attachment flange 22. The axis 24 is also
6 the central flow line of production fluid when production fluid flows through the flexible
7 pipe joint. The flexible pipe joint has a laminated elastomeric flex element 25 interposed
8 between an upper semispherical portion of the pipe extension 23 and an internal seat 27
9 in the body 21. The internal seat 27 is annular and symmetric about the central axis 24,
10 and has a spherically curved surface that is complementary to the semispherical portion
11 26 of the pipe extension 23. A metal seal ring 37 such as an API BX gasket ensures
12 pressure sealing of the attachment flange 22 to the body 21.

13 **[00033]** In operation, the production fluid flowing up the pipe extension 23 and
14 through the bore 30 is pressurized, and a relatively incompressible fluid 28 in an annular
15 cavity within the body 21 is also pressurized. The fluid 28 should have a higher boiling
16 point than the maximum steady-state temperature of the production fluid. In order to
17 prevent mixing of the relatively incompressible fluid 28 with the production fluid, a
18 bellows 29 is secured between the semispherical portion 26 of the pipe extension 23 and
19 the attachment flange 22, and the bellows encloses a cylindrical extension 39 of the
20 attachment flange. At least four holes 31, 32 are drilled through the cylindrical extension
21 30 so that the internal pressure within the bellows 29 is substantially equal to the
22 production fluid pressure. The lower half of the bellows 29 has a relatively large
23 diameter and the upper half of the bellows has a relatively small diameter so that any

1 substantial pressure difference between the production fluid and the relatively
2 incompressible fluid 28 within the body 21 is equalized by upward or downward
3 movement of the middle portion of the bellows 29.

4 [00034] Although the primary purpose of the bellows 29 is to prevent damage
5 to the elastomer in the event of explosive decompression of the production fluid, the
6 bellows also functions as a heat shield by shielding the elastomeric flex element 25 from
7 the hot production fluid.

8 [00035] In a conventional flexible joint using a bellows, the inner annular
9 cavity is typically filled with a non-corrosive glycol-based fluid, such as an aqueous
10 propylene glycol solution. At high temperatures, however, propylene glycol slowly
11 breaks down to acid. For high temperature operation, a polyalkylene glycol solution is
12 preferred, such as Union Carbide UCON brand heat transfer fluid No. 500.

13 [00036] In order to shield the upper semispherical portion of the pipe extension
14 26 from the production fluid, a heat shield 33 is seated within the upper end of the pipe
15 extension. The heat shield 33 includes a hemispherical portion mating with an inner
16 profile of the hemispherical portion 26 of the extension pipe, and the heat shield 33 also
17 includes a cylindrical portion extending into the cylindrical portion of the extension pipe
18 23. The heat shield 33 contacts the lower end of the cylindrical extension 39 of the
19 attachment flange 22, and this contact places the flex element 25 in an initial state of
20 compression before assembly of the flexible pipe joint 18 into a riser.

21 [00037] In order to further reduce the flow of heat from the production fluid to
22 the elastomeric flex element 25, the upper portion 26 of the extension 23 and also the
23 bellows 29 can be made of low heat conductivity metal such as nickel-chromium-iron

1 alloy. The preferred nickel-chromium-iron alloy is Inconel brand alloy, which contains a
2 minimum of 72% nickel and cobalt, 14 – 17% chromium, and 6 – 10% iron, such as 76%
3 nickel, 17% chromium, and 7% iron. For example, a weld 38 attaches the Inconel alloy
4 upper portion 26 of the pipe extension 23 to the lower portion 37 made of ASTM A707
5 steel.

6 [00038] As further shown in FIG. 3, a series of annular baffles 34 can be
7 secured to the inner cylindrical surface of the body 21 to set up a favorable convective
8 flow pattern in the fluid 28. This flow pattern promotes the transfer of heat from the
9 bellows 29 to the body 21 and from the flex element 25 to the body 21 without promoting
10 the transfer of heat from the bellows 29 to the flex element 25. The surface area of the
11 baffles 34 also promotes transfer of heat from the fluid 28 to the body 21 near a relatively
12 high temperature region of the elastomer flex element 25.

13 [00039] FIG. 4 is a magnified view of an upper bellows seal area 35 in FIG. 3.
14 The lower surface of the attachment flange has an annular groove filled with relatively
15 soft metal seat 41 that makes a metal-to-metal seal with an upper ring 42 of the bellows
16 29. A seal ring 43 is received in a groove in the ring 42 and is held against the seat 41.
17 The seal ring 43, for example, is made of temperature resistant rubber such as peroxide
18 cured hydrogenated nitrile butadiene rubber (HNBR). The ring 42 is held in place by a
19 clamping ring 44 bolted to the attachment flange 22. To facilitate assembly, a ring 45 is
20 fastened to the upper ring 42 of the bellows to retain the clamping ring 44 in close
21 proximity to the upper ring 42 of the bellows.

22 [00040] FIG. 5 is a magnified view of a lower bellows seal area 36 in FIG. 3.
23 The bellows 29 has a lower ring 51 having an annular groove containing a seal ring 52.

1 The seal ring 52, for example, is made of temperature resistant rubber such as peroxide
2 cured hydrogenated nitrile butadiene rubber (HNBR). The lower ring 51 is bolted to a
3 retaining ring 53 secured by a weld 54 to the semispherical upper portion 26 of the
4 extension pipe. The lower ring 51 and the retaining ring 53 can be made of low heat
5 conductivity metal such as Inconel alloy.

6 **[00041]** The retaining ring 53 retains a multi-section lock ring 55 fitted over the
7 heat shield 33. Force-fitted pins 56 connect the sections of the multi-section lock ring 55
8 to the heat shield 33. In addition, a layer of adhesive 57 bonds the heat shield 33 and the
9 multi-section lock ring 55 to the semi-spherical upper portion 26 of the extension pipe.
10 The adhesive 57 is a high temperature epoxy such as Araldite 2014 from Ciba Specialty
11 Chemicals Corporation. Araldite 2014 is produced by Vantico Inc., 4917 Dawn Ave.,
12 East Lansing, Mi, 48823.

13 **[00042]** Preferably the heat shield 33 is made of polyetheretherketone (PEEK)
14 reinforced with 30 percent of randomly-oriented chopped glass fiber. This amount of
15 chopped glass fiber reduces creep to acceptable limits when the heat shield 33 is exposed
16 to high temperature production fluid of at least 235 °F (113 °C). The lock ring 55 and
17 pins 56 are made of the same PEEK material. The PEEK material, for example, is grade
18 450GL30 produced by Victrex plc, at Hillhouse International, Thornton Cleveleys,
19 Lancashire, FY5 4QD England. The PEEK material is compression molded to
20 appropriate dimensions. In addition, the mating surfaces of the heat shield 33 and the
21 upper portion 26 of the pipe extension are machined for a close fit.

22 **[00043]** Instead of PEEK, the heat shield 33 could be made from
23 polytetrafluoroethylene such as TEFLON brand polytetrafluoroethylene. The heat shield

1 in combination with the other heat reduction features of FIG. 3 should reduce the
2 maximum temperature of the elastomeric flex element to 200 °F (93 °C) for a 220 °F
3 (104 °C) production fluid temperature and an ambient seawater temperature of 85 °F (47
4 °C).

5 [00044] FIG. 6 is an exploded view of the components associated with the heat
6 shield 33. The multi-section lock ring 53 includes four sections 61, 62, 63, 64, and two
7 respective pins connect each section to the heat shield 33.

8 [00045] FIG. 7 shows the alternate elastomer layers 71, 73, 75, 78 and steel
9 reinforcing layers 72, 74, 75, 77 of the elastomeric flex element 25. The elastomer layer
10 71 is the layer that is bonded to the semispherical upper portion (26 in FIG. 3) of the
11 extension pipe, and the elastomer layer 78 is the layer that is bonded to the seat (27 in
12 FIG. 3) of the body. Therefore, when conveying high temperature production fluid in a
13 subsea environment, there will be a temperature gradient across the elastomeric flex
14 element 25. The elastomer layer 71 will have the highest temperature, and the elastomer
15 layer 78 will have the lowest temperature. This temperature gradient is non-uniform,
16 such that the higher temperatures are concentrated in the first few inner elastomer layers
17 71, 73. The increased temperature reduces the modulus of the elastomer, and the reduced
18 modulus reduces internal stress and extends fatigue life.

19 [00046] Despite the modulus-induced softening of the inner elastomer layers, it
20 is desired to keep the elastomer shear strain substantially uniform across the elastomeric
21 flex element 25 during use of the flexible joint. It is also desired to keep the elastomer
22 shear strain below a design limit such as 200% for extreme bending of the pipe extension
23 with respect to the body. Moreover, there is an advantage for the inner elastomer layers

1 71, 73, to be thicker than the outer elastomer layers 76, 78. Thicker inner elastomer
2 layers act as a heat shield for the outer elastomer layers due to the relatively low heat
3 conductivity of the elastomer. Thicker inner elastomer layers may also reduce the direct
4 shear strain on the elastomer.

5 [00047] In view of these considerations, it is preferred to use a relatively high
6 modulus elastomer compound for the initial inner layers 71, 73, an increased number of
7 elastomer layers and metal reinforcements in comparison to a conventional flex element
8 handling the same loads, an increased elastomer thickness for the initial inner layers in
9 comparison to the outer layers 76, 78, and a greater shear area than is conventional for the
10 initial inner layers.

11 [00048] For example, the elastomeric flex element 25 has an inner spherical
12 radius of 16 inches (40.6 cm) and an outer spherical radius of 25 inches (63 cm). The
13 elastomeric flex element 25 has metal reinforcements having a thickness in the range of
14 0.15 to 0.20 inches (3.8 to 5 mm), and elastomer layers having a thickness in the range of
15 0.07 to 0.20 inches (1.8 to 5 mm). All of the metal reinforcements can have the same
16 thickness. Preferably the thickness of the elastomer layers varies over a range of about
17 30% to 50% with thicker inner layers and thinner outer layers.

18 [00049] For example, the elastomeric flex element 25 has thirty elastomer
19 layers and twenty-nine steel reinforcements. All of the metal reinforcements have the
20 same thickness. All of the seven innermost elastomer layers have the same thickness and
21 the same nominal shear modulus (i.e., the modulus at room temperature) of 250 psi. All
22 of the eight middle elastomer layers have the same thickness and the same nominal shear
23 modulus of 220 psi. All of the fifteen outermost elastomer layers have the same thickness

1 and the same nominal shear modulus of 200 psi. The thickness of the middle elastomer
2 layers is the average of the thickness of the innermost elastomer layers and the outermost
3 elastomer layers.

4 [00050] The elastomeric flex element 25 has a greater shear area for the inner
5 elastomer layers 71, 73, than is conventional due to the relatively large surface area of the
6 inner elastomer layer 71 in contact with the upper portion 26 of the pipe extension in
7 comparison to the surface area of the outer elastomer layer 78 in contact with the internal
8 seat 17 of the body 21 (see FIG. 3).

9 [00051] The modulus of the elastomer is selected by adjusting the amount of
10 carbon black and/or silica filler in the elastomer. The modulus can be adjusted over about
11 a three to one range by adjusting the amount of carbon black and/or silica filler from
12 about 5 parts per hundred to 55 parts per hundred. The modulus is lowered by decreasing
13 the amount of filler. For nitrile butadiene rubber (NBR), carbon black in the range of
14 about 40 to 45 parts per hundred is used to obtain the modulus of 200 to 250 psi. As
15 shown in FIG. 8, for example, the inner elastomer layers 71, 73 have a good amount of
16 carbon black filler particles 80, and the outer elastomer layers 76, 78 have a lesser amount
17 of carbon black filler particles. The thickness of the inner elastomer layers 71, 73 is
18 greater than the thickness of the outer elastomer layers 76, 78.

19 [00052] There may be some situations where it would be desirable to make the
20 inner elastomer layers thinner than the outer elastomer layers. This may occur if there
21 would be a pressure constraint due to the combination of production fluid pressure, riser
22 tension, and maximum extension pipe deflection angle, that would require thin inner
23 elastomer layers to prevent rupturing of the inner elastomer layers at the extreme inner or

1 outer edges of these layers, especially at the extreme inner elastomer edges of these inner
2 elastomer layers at the elastomer-seawater interface.

3 [00053] The high temperature flexible pipe joint as described above with
4 reference to FIGS. 2 to 8 can be fabricated in the following sequence. The metal
5 forgings, a flex element mold, bellows 29, heat shield components 33, 53, 56, bolts and
6 miscellaneous hardware are ordered from selected vendors, who fabricate these
7 components to supplied drawings. The elastomeric material is also ordered from a
8 supplier. The forging for the extension pipe 23 is received, inspected, and internally clad
9 with Inconel alloy. The Inconel retainer ring 53 is then welded to the upper end 26 of the
10 extension pipe. The heat shield components 33, 53, 56 are received, inspected, and
11 installed in the upper end of the extension pipe using high temperature epoxy and cured
12 under vacuum. All of the metals are then cleaned and prepared for the molding and
13 assembly process. The elastomeric flex element 25 is built up using high temperature
14 elastomer compounds and forged steel reinforcements. The flex element, the body 21 and
15 the extension 23 are assembled into the mold, and the assembly is placed in a horizontal
16 press. The flex element is then molded in contact with the body and the extension and
17 cured by heat and pressure. After curing, the assembly of the flex element, body and
18 extension are removed from the mold, inspected, and painted with a rust inhibiting paint.
19 This assembly is tested for stiffness at ambient temperature without pressure. Once this
20 test is passed, the bellows 29 is attached to the upper end 26 of the extension pipe, the
21 bellows is attached to the attachment flange 22, the incompressible fluid 28 is added, and
22 then the attachment flange is bolted to the body. The flexible pipe joint is then pressure
23 tested to its maximum design limit.

1 **[00054]** The flexible pipe joint as described above could be modified in various
2 ways. As shown in FIG. 9, for example, the inner elastomer layers 91, 93, 95, and 97
3 could have a composition 100 that is different from the composition of the outer layers
4 99. For example, the inner elastomer layers could be made of peroxide-cured
5 hydrogenated nitrile butadiene rubber (HNBR), and the outer elastomer layers could be
6 made of semi-efficient or conventionally vulcanized nitrile butadiene rubber (NBR).

7 **[00055]** It is desirable to use elastomeric compounds that provide greater
8 temperature tolerance at least for the inner elastomer layers 71, 73. For example,
9 conventional flexible joints are typically made of vulcanized natural rubber compositions
10 or vulcanized nitrile butadiene rubber compositions. In general, heat aging and
11 compression set resistance of vulcanized rubber compositions can be increased by using
12 efficient vulcanization, at the expense of low temperature crystallization resistance and
13 higher extension ratios. Efficient vulcanization creates a cured elastomer having a high
14 ratio of monosulfidic crosslinks to poly and disulfidic crosslinks, for example, four times
15 as many monosulfidic crosslinks than poly and disulfidic crosslinks. An example of
16 efficient vulcanization for increasing the temperature tolerance of natural rubber
17 compositions is given in Nozik U.S. Patent 6,346,567, incorporated herein by reference.
18 In a similar fashion, efficient vulcanization of nitrile butadiene rubber can be used for
19 fabricating the flex element 25 shown in FIGS. 7 and 8. This should provide long-term
20 temperature resistance for elastomer temperatures up to about 200 °F (93 °C).

21 **[00056]** There are various kinds of elastomer that have published continuous
22 temperature tolerance that is better than natural or nitrile butadiene rubber. However, the
23 published continuous temperature for heat resistance of an elastomer usually refers to

1 retention of elastomer properties such as shear modulus over at most hundreds of hours.
2 The published continuous temperature resistance over hundreds of hours does not
3 quantify the continuous temperature resistance over a service life of twenty years. The
4 published values are useful, however, for comparison between different kinds of
5 elastomer to identify those kinds that may be most useful in increasing the temperature
6 tolerance of the elastomeric flex element. In general, testing is needed to quantify the
7 continuous maximum temperature that is permissible over a service life of twenty years
8 for any particular kind of elastomer.

9 [00057] . In general, to increase the permissible operating temperature for a
10 conventional elastomeric flexible joint simply by substituting an elastomer of higher
11 temperature tolerance, the elastomer must have a number of properties that cannot be
12 substantially degraded over the desired service life. These properties include elastomer
13 tensile strength, modulus softening resistance, fatigue resistance, creep resistance, and
14 strength of the elastomer-metal bond between the elastomer layers and the metal
15 reinforcements. Also, it is desired for the elastomer to be chemically resistant to
16 hydrocarbon production fluid, in order to prevent rapid failure of the elastomeric flex
17 element in case production fluid would leak through the bellows or upper or lower
18 bellows seal into the inner annulus and come into contact with the elastomeric flex
19 element. For example, nitrile butadiene rubber (NBR), hydrogenated nitrile butadiene
20 rubber (HNBR), and fluoroelastomer all have excellent resistance to hydrocarbon
21 production fluid. Most silicone elastomers have poor resistance to hydrocarbon
22 production fluid.

1 **[00058]** Peroxide cured hydrogenated nitrile butadiene rubber (HNBR) has
2 increased high temperature tolerance over NBR. Testing with peroxide cured HNBR,
3 however, revealed a fabrication problem with a large flex element that was not observed
4 with a smaller flex element. In particular, fabrication of a HNBR flex element for a 12
5 inch high temperature flexible joint had a problem of uniform bonding of the elastomer to
6 the metal reinforcements.

7 **[00059]** For natural rubber and nitrile butadiene rubber, there are a number of
8 bonding agents for producing elastomer-metal bonds that retain bond strength at high
9 temperatures. One such bonding agent is Chemlock 205/TY-PLY-BN produced by Lord
10 Corporation, 2000 W. Grandview Blvd., P.O. Box 10038, Erie, PA. Another is Thixon
11 P-6-EF primer and 532-EF adhesive produced by Rohm and Haas Company, 100
12 Independence Mall West, Philadelphia, PA 19106. For example, the metal
13 reinforcements are prepared by solvent cleaning, then abrasive blasting, then further
14 solvent cleaning, then applying primer, and then applying adhesive. The prepared metal
15 reinforcements are then placed in a mold with elastomer mix. The mold is pressurized
16 and cured at 250 °F (121 °C) for 70 min.

17 **[00060]** There are some temperature resistant elastomers that have very good
18 temperature resistance but have relatively poor bonding to metal, such as some
19 fluoroelastomers. There are also some temperature resistant elastomers that are so new
20 that adhesive systems have yet to be developed or sufficiently tested to ensure retention of
21 sufficient bond strength under high temperature conditions over a desired twenty-year
22 service life. An example of a relatively new high temperature elastomer is linear poly-

1 silarylene-siloxane-acetylene as described in Keller U.S. Patent 6,579,955, incorporated
2 herein by reference.

3 [00061] To some degree, the physical configuration of the elastomeric flex
4 element can be altered to compensate for a deficiency in some of the desired properties of
5 the temperature resistant elastomer, such as poor bonding or poor strain resistance. For
6 example, the strain in most fluoroelastomers should be limited to about 30 percent.

7 [00062] FIG. 10 shows an alternative high temperature flexible pipe joint 120
8 that may use a temperature resistant elastomer that has relatively poor elastomer to metal
9 bonding or poor strain resistance. The flexible pipe joint 120 has a body 121 and an
10 extension pipe 122. The extension pipe 122 has an upper semispherical portion 123
11 having an outer surface 124 mating with an elastomeric flex element 125 resting on an
12 inner seat 128 of the body 121. The elastomeric flex element has an inner high
13 temperature portion 126 and an outer low temperature portion 127. The inner high
14 temperature portion 126 is comprised of alternate layers of temperature resistant
15 elastomer and metal reinforcement rings. The outer surface 134 of the upper portion 123
16 of the pipe extension 122 is formed with concentric circular corrugations about the
17 longitudinal axis 129 of the pipe extension. The flexible pipe joint 120 has an inner
18 attachment flange extension 130 that contacts a heat shield 131 to put the elastomeric flex
19 element 125 in an initial state of compression and thus maintain a good seal between the
20 external environment and substantially incompressible fluid 132 inside the body 121.

21 [00063] As more clearly seen in FIG. 11, the alternate layers of temperature
22 resistant elastomer 141, 143, 145, 147 such as fluoroelastomer, and metal reinforcing rings
23 142, 144, 146, 148 of the high temperature portion 126 of the elastomeric flex element

1 125 are also corrugated or pocketed to conform to the corrugations on the outer surface of
2 the upper portion 123 of the pipe extension. The elastomer layers and reinforcements
3 could be corrugated or pocketed in various ways different from the example shown in
4 FIG. 11; for example, the reinforcements could have a waffle-iron configuration. When
5 biased in a compressive state, the corrugations or pockets permit shear forces to be
6 transmitted between the corrugated elastomer and metal layers 141 to 148 without
7 adhesive bonding between these layers. The corrugated or pocketed structure also
8 provides greater shear area in order to make the high temperature portion 126 of the
9 elastomeric flex element relatively stiff and limit the strain on the high temperature
10 elastomer layers relative to the stiffness and strain on the low temperature elastomer
11 layers in the low temperature portion 127 of the elastomeric flex element. The low
12 temperature portion 127 of the elastomeric flex element may have a conventional
13 construction and may use low temperature elastomer such as vulcanized nitrile butadiene
14 rubber (NBR).

15 [00064] FIG. 12 shows an alternative construction for heat shielding of the
16 upper portion 151 of an extension pipe in a high temperature flexible pipe joint. The heat
17 shielding includes low heat conductivity ceramic material 152 such as silica or ceramic
18 fiber that is fused together. Such ceramic material is capable of withstanding
19 considerable compressive force but it is not suitable for direct contact with the lower end
20 of the inner extension of an attachment flange (39 in FIG. 3). Therefore, the entire outer
21 surface of the ceramic material 152 is coated with high temperature epoxy 153 and
22 bonded between an outer metal cover 155 and the inner surface of the upper portion 151
23 of the pipe extension. The outer metal cover 155 is then welded to the upper portion of

1 the pipe extension at an upper location 156 and at a lower location 157. Preferably, the
2 outer metal cover 155 is made of low heat conductivity metal such as Inconel alloy.

3 [00065] FIG. 13 shows another alternative construction for heat shielding of the
4 upper portion 161 of an extension pipe in a high temperature flexible pipe joint. In this
5 case, there is a good deal of "dead space" between the upper portion 161 of the extension
6 pipe and a metal cover 162. A number of metal reinforcing rings 163, 164, 165, 166, and
7 167 transmit compressive force from the cover 162 to the upper portion of 161 of the
8 extension pipe. The cover 162 is welded to the upper portion of the pipe extension at an
9 upper location 168 and a lower location 169. The cover 162 and the reinforcing rings 163
10 to 167 are made of low heat conductivity metal such as Inconel alloy. The dead space
11 between the upper portion 161 of the extension pipe and the metal cover 162 includes a
12 number of cavities that could be filled with gas or evacuated to reduce convective heat
13 transmission. Moreover, as shown in FIG. 16, packing the dead space with layers of heat
14 reflective metal foil and fiberglass insulation 170 could reduce heat transmission through
15 the dead space.

16 [00066] Another way of reducing the temperature of the elastomeric flexible
17 joint is to reduce the thermal resistance of the path through the body from the relatively
18 incompressible fluid in the inner annulus to the external seawater environment. For
19 example, FIG. 14 shows a high temperature flexible pipe joint 180 having a body 181, an
20 attachment flange 182, and an extension pipe 183. The body 181 is formed with an array
21 of external fins 184 about its outer circumference for dissipation of heat from the body
22 181 to the external seawater environment. A set of fins 185 are also attached around the
23 extension pipe 183. The fins 185 around the extension pipe 183 not only help cool the

extension pipe but may also stir up some circulation of seawater during flexing of the extension pipe 183 relative to the body 181, and this circulation may help cool the bottom of the body 181.

[00067] As further shown in FIG. 15 and FIG. 16, the inner surface of the body 181 is milled to form internal fins 186 that promote the transfer of heat from the incompressible fluid 188 in the inner annulus to the body 181. As best seen in FIG. 15, the internal fins also support baffles 187 that organize convective currents in the fluid 188. Propelling seawater across the external fins 184 and 185 could provide additional cooling of the body 181 or the extension pipe 183. It would also be possible to form channels in the body 181 and pump coolant through the channels to reduce the temperature of the body below the temperature of the seawater environment.

[00068] In view of the above, there has been described a flexible pipe joint having a combination of feature that permit continuous high temperature operation over a service life in excess of twenty years. These features contribute to a significant reduction in the steady-state temperature of the load-bearing flex element or strain reduction in the warmer elastomeric layers of the flex element. These features include a heat shield of low heat conductivity material (polymeric, ceramic, etc.) or gaseous filled or vacuum cavity integrated into the inner profile of the pipe extension and interposed between the central bore of the pipe joint and the elastomeric flex element. Low heat conductivity metal alloy components replace standard steel components that act as a proximate interface between the hot production fluid and the flex element. The elastomeric flex element may include high temperature resistant elastomer at least in an inner layer of the flex element proximate to the hot production fluid. The elastomeric flex element may

1 also shift the burden of alternating strain from the warmer inner elastomer layers to the
2 colder outer elastomer layers by providing greater shear area, different layer thickness,
3 and/or higher elastic modulus elastomer composition for the warmer inner elastomer
4 layers. A bellows typically provided for preventing damage to the flex element during
5 any explosive decompression also provides shielding of the elastomeric flex element
6 from the hot production fluid. This bellows can be made of low heat conductivity metal.
7 The internal annular cavity around the bellows can be filled with a commercially
8 available, relatively incompressible, high temperature stable fluid.

9